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Enhancements of magnetospheric convection electric field associated with sudden commencements in the inner magnetosphere and plasmasphere regions

A. Shinbori *, T. Ono, M. Iizima, A. Kumamoto, Y. Nishimura

Department of Astronomy and Geophysics, Gradual Institute of Geophysics, Tohoku University, Sendai, Miyagi 980-8578, Japan

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Abstract

Electric field variations in the inner magnetosphere and plasmasphere regions associated with sudden commencements (SCs) are investigated by using the observation data of the Akebono satellite which has been carried out more than 15 years since 1989. 117 of 153 SC events in the low-latitude (MLAT < 45°) region, which occurred within a period from March 1989 to January 1996, showed a shift of the magnetospheric convection electric field with the magnitude of 0.1–3.2 mV/m about 1 min after the electric field signature with a bi-polar waveform due to the passage of fast-mode hydromagnetic (HM) waves. The increase of the convection electric field takes place in the entire magnetic local time sector in the inner magnetosphere. The amplitude does not depend on *L*-value and magnetic local time but is proportional to the SC amplitude measured at Kakioka. The majority of the electric field enhancements persist for about 4–14 min. The origin of the convection electric field in the inner magnetosphere is a plasma motion caused by the compression of the magnetosphere due to the solar wind shock and discontinuity.

Keywords: Sudden commencement; Convection electric field; Plasmasphere; Inner magnetosphere; Solar wind shock

1. Introduction

Study on the DC electric and magnetic field variations which directly affect on the dynamics of the magnetosphere and plasmasphere plasmas as well as the ionospheric plasma via the magnetosphere–ionosphere coupling processes is essential for understanding of physical processes of transport of mass, momentum and energy in the magnetosphere. Due to the arrival of an interplanetary shock wave and discontinuity of solar wind to the earth's magnetopause, fast-mode hydromagnetic (HM) waves are generated in the dayside magnetopause region. Then, they propagate toward the earth passing through the magnetosphere, plasmasphere and ionosphere. When they arrive on the ground, the signature of sudden commencements (SCs) is recorded on the magnetogram at low-latitude regions giving an abrupt increase of geomagnetic H-component within a few minutes. The magnetic field variations on the ground at both the dayside equator and high-latitude regions associated with SCs are observed as two pluses which consist of the preliminary impulse (PI) and the main impulse (MI) (Matsushita, 1957a,b; Wilson and Sugiura, 1961; Sano, 1964; Araki, 1977, 1994; Araki and Allen, 1982). The passage of the fast-mode HM waves leads magnetic and electric field perturbations (e.g., Wilken et al., 1982; Knott et al., 1985; Kikuchi, 1986; Schmidt and Pederson, 1987; Laakso and Schmidt, 1989; Cahill et al., 1990; Araki, 1994; Wygant et al., 1994; Fujita et al., 2003a; Shinbori et al., 2003a, 2004) and plasma wave phenomena in ULF, ELF,

* Corresponding author. Tel.: +81 22 217 6516; fax: +81 22 217 6517.
E-mail address: atsuki@stpp1.geophys.tohoku.ac.jp (A. Shinbori).

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VLF and HF ranges (e.g., Hirasawa, 1981; Gail et al., 1990; Gail and Inan, 1990; Wilson et al., 2001; Shinbori et al., 2002, 2003a,b) in the magnetosphere. Shinbori et al. (2004) reviewed the recent studies on the electric field phenomena associated with SCs, based on the satellite observations. From a statistical analysis based on the long-term satellite observations, Shinbori et al. (2004) showed that the initial excursion of the electric field during SCs with the magnitude of 0.2–38 mV/m tends to be directed westward in the plasmasphere, and that the Poynting vector of the initial SC impulse is directed toward the earth, which suggests that energy of magnetic disturbances associated with SCs propagates toward the earth inside the plasmasphere with the refraction due to the plasma density gradient. Shinbori et al. (2004) also found a DC offset of the background E_y component with the magnitude of 0.5–2.0 mV/m after the initial excursion of the electric field perturbations associated with SCs. On the other hand, appearance of the convection electric field enhancements in the ionosphere and inner magnetosphere during the MI phase has been predicted based on ground observations (e.g., Kikuchi, 1986; Araki, 1994) and numerical simulation (Fujita et al., 2003b). However, signatures of these enhancements of the background E_y field or convection electric field in the inner magnetosphere and plasmasphere regions after the SC onsets have not been fully understood. In this paper, electric and magnetic field phenomena associated with SCs are studied by using electric field (Hayakawa et al., 1990) for more than 15 years of the Akebono satellite observations with high time resolution. In the analyzed data, 117 cases of the electric field perturbations associated with SCs have shown an enhancement of the background E_y component after SC onsets.

The purpose of the present study is to investigate the detail signatures of the enhancements of the background E_y component which is interpreted as representing the magnetospheric convection electric field in the inner magnetosphere and plasmasphere associated with SCs, and to clarify the origin of the enhanced convection electric field after the onset of SCs observed by the Akebono satellite.

2. Observation data

2.1. Akebono satellite data

Observations of the Akebono satellite have been continued more than 13 years since the launch on February 21, 1989 when the satellite was put into a semi-polar orbit with an inclination of 75°, with initial apogee and perigee of 10,500 and 274 km, respectively. In the present studies, electric and magnetic field data are provided by instruments of EFD (Hayakawa et al., 1990) and MGF (Fukunishi et al., 1990), respectively. The time resolution of the EFD and MGF data from the science database of the Akebono satellite is 8 s. The data are presented in the Geocentric Solar Magnetospheric (GSM) coordinate system. The electric field measurement is made by two sets of double probes in the spin plane of the Akebono satellite. The spin axis component (the E_x component) has been calculated under the assumption of zero electric field along the magnetic field line, namely $\mathbf{E} \cdot \mathbf{B} = 0$. The accuracy of the electric field data is 0.1 mV/m. In this paper, we plotted the electric field intensity of the dawn-to-dusk component in a corotating frame as a function of L-value mapped to the equatorial region of the inner magnetosphere by using the mapping method proposed by Mozer (1970).

2.2. Identification of SC events

Within a period from January 1989 to December 2002, 2803 SC events have been identified in term of SYM-H (Iyemori and Rao, 1996) with the time resolution of 1 min. We picked up SC events as a rapid increase of SYM-H value with more than 5 nT within 10 min as has been described by Shinbori et al. (2002, 2003b). For each SC event, the precise onset time was identified by referring the H-component geomagnetic variation from the rapid sampling records with the time resolution of 1 s obtained at Kakioka Magnetic Observatory. The way of the detailed determination of the onset time has been described by Shinbori et al. (2002, 2003b). Among 276 low-latitude SC events within a period from March 1989 to December 2002, the electric field data were available for 161 cases of the SC events. 153 cases of the 161 SC events show clear changes of the magnitude and direction of the electric field with correspondence to the enhancements of SC related plasma waves. Furthermore, 117 cases of the 153 SC events indicate clear enhancements of the electric field after the signatures of the SC related electric field perturbations.

3. Enhanced convection electric field associated with SCS

3.1. Examples of SC related $\mathbf{E}_y$ field variations

3.1.1. SC event at 17:49:03 (UT) on December 1, 1989

Fig. 1 shows an example of electric field signatures in the inner magnetosphere associated with SC which occurred at 17:49:03 (UT) on December 1, 1989. In this case, the Akebono satellite observation point was located at $L = 2.6$, 05:32 (MLT) and 1.0° (MLAT) just near the magnetic equator region of the plasmasphere around the SC onset. The panels (a)–(d) in Fig. 1 indicate geomagnetic field variations of the H-component measured at Kakioka, electric fields of the E_x and E_y